NRRA
Level 3-4 ICMV Evaluation

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Outlines

• Project Overview
• Classification System of ICMV
• Work Plan - Level 3-4 ICMV Prototypes
• Work Plan - Field Validation
• Project Schedule Update
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Level 3-4 ICMV Study

- MNDOT Contract No. 1034039
- Title: Evaluation of Levels 3-4 Intelligent Compaction Measurement Values (ICMV) for Soils Subgrade and Aggregate Subbase Compaction
- Project Period: 36 Months
- Objectives
  1. Evaluate Level 3-4 ICMV systems against Level 1-2 ICMV systems for soils and base compaction,
  2. Develop a blue print for future certification procedures of IC.
**Project Team**

**MNDOT**
- Lois Butcher – Project Manager
- Rebecca Embacher – Technical Liaison

**Panel**
- John Siekmeier, MNDOT
- Jordan Nehls, NDDOT
- Ervin Dukatz, Mathy Construction

**Research Team**
- George K. Chang - PI
- Soheil Nazarian - Co-PI

**Industry Partners**
- Todd Mansell, CAT
- Nick Oetken, CAT
- David Shelstad, MOBA
- Lige Xue, XCMG
- GH Xu, SineCore
Research Team Structure

Lois Butcher
MnDOT Project Manager

Dr. George K. Chang, P.E.
PI Transtec

Prof. Soheil Nazarian, Ph.D., P.E., D.GE
Co-PI UTEP

Amanda Gilliland, P.E.
Project Engineer Transtec

Sergio Rochas, BSEE
Jr. Professional UTEP

Dr. Abbas TaghaviGhalesari
Project Engineer Transtec

Prathmesh Jickar
Research Staff UTEP
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• **Classification System of ICMV**
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ICMV Mechanism

- **Intelligent Compaction Measurement Value**

![Diagram of ICMV Mechanism](image)

- Control System
- ICMV
- Roller Drum
- Accelerometer
- Compacted Materials
- Compaction & reaction force
- Correlation with materials modulus & density
Influence Factors on ICMV

- Soils type and Moisture Content
- Mix proportioning
- Temperature
- Support Condition
- Vibration frequency
- Temperature
- Soils type and Moisture Content
- Vibration frequency
Challenges for Measuring ICMV

Actual measurement ≠ Theoretical computation
ICMV Road Map

FHWA-HIF-17-046
Level 1-2 ICMV
Empirical solution based on frequency ratios
Empirical solution based on energy method and rolling resistance

Level 3 ICMV
Mechanistic solutions based on static or dynamic methods expressed in stiffness, reactional force, or modulus

Level 4 ICMV
Mechanistic solutions based static method with impact model expressed in reactional force or modulus

Level 5 ICMV
Mechanistic solutions based on dynamic methods and artificial intelligence expressed in density or modulus

Source: FHWA-HIF-17-046
Criteria for Levels of ICMV

• Correlation: The threshold value for coefficient of correlation between ICMV and in-situ spot tests is generally accepted as $R = 0.70$ or $R = 0.5$.

• Decouple: Produce valid solution of ICMV during double-jump or decouple when the roller drum and compacted material lose contact.

• Layer Specific: Produce layer-specific ICMV values.

• Advanced IC: The ICMV can be combined with advanced technologies such as Artificial Intelligence and auto-feedback controls.
# Levels of ICMV

<table>
<thead>
<tr>
<th>Level</th>
<th>Model</th>
<th>Measurement Values</th>
<th>Correlation¹</th>
<th>Decouple²</th>
<th>Layer Specific³</th>
<th>Advanced IC⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Empirical</td>
<td>Harmonic ratio</td>
<td>O</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>2</td>
<td>Energy</td>
<td>Energy index</td>
<td>?</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>3</td>
<td>Discrete vibration</td>
<td>Stiffness Coefficient</td>
<td>✓</td>
<td>×</td>
<td>×</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Steel drum movement</td>
<td>Resistance force</td>
<td>✓</td>
<td>✓</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Continuous static</td>
<td>Modulus</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>Hybrid</td>
<td>Resistance force, Modulus</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>Continuous dynamic</td>
<td>Density, Modulus</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

1. Correlation: The threshold value for coefficient of correlation between ICMV and in-situ spot tests is generally accepted as $R = 0.70$ or $R = 0.5$.
2. Decouple: Produce valid solution of ICMV during double-jump or decouple when the roller drum and compacted material lose contact.
3. Layer Specific: Produce layer-specific ICMV values.
4. Advanced IC: The ICMV can be combined with advanced technologies such as Artificial Intelligence and auto-feedback controls.
5. $\times$: No or Bad, $O$: Satisfactory, $?$: Unproven; $✓$: Yes or Good.
Level 1 ICMV - Empirical Reactive Model

e.g. CMV, HMV, CCV
Level 2 ICMV - Energy Model

\[ f_1 = C_1 \]
\[ f_2 = C_2 \]
\[ f_3 = C_3 \]
\[ f_4 = C_4 \]

E.g. MDP
Level 3 ICMV - Discrete Model

e.g. $K_b$, $E_{vib}$, SineCore-3
Level 4 ICMV - Collision Impact Model

e.g. SineCore-4
Level 5 ICMV – AI-Enhanced Model

Drum impact movements

Force diagram

Compute reactive force

Prototype:
NCHRP 24-45
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IC Rollers

- Caterpillar single drum roller with CMV (and/or MDP?)
- XCMG single drum roller with Level 3-4 ICMV prototype
MOBA IC Retrofit

1. Touch screen display
2. GNSS antenna
3. WIFI antenna (optional)
4. GSM antenna (optional)
5. Uninterruptible power supply
6. T-connector (optional)
7. IR temperature sensor (optional)
8. Acceleration sensor (optional)
Level 3-4 ICMV Prototypes

• MOBA IC retrofit system prototype with SINE CORE ICMV module

• XCMG OEM IC system prototype with SINE CORE ICMV module

• UTEP DAQ system - Computed Stiffness values
SINE CORE Level 3-4 ICMV Modules
SINE CORE Level 3-4 ICMV Module

Re-Designed with Highspeed Triaxial Accelerometers
Free of influence from Earth’s gravitational acceleration signals
SINE CORE Inputs and Outputs

Inputs:
- Roller Parameters
- Acceleration
- Temperature

Outputs:
- Resistance force factor $F_R$
- Stiffness $K_R$
- Modulus $E_R$
Integration of Level 3-4 ICMV
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Field Test Site

- Field site with Subgrade and Base construction

- 250 ft X 25 ft

- MN Test Site in 2021
# Field Schedule and Activities

<table>
<thead>
<tr>
<th>Time</th>
<th>Tasks</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Days before First Visit</td>
<td>Coordination and Initial Set up</td>
<td>• Mark the test section and spot test locations (research team)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Arrange for field and roller instrumentation (MnDOT, research team)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Obtain GPS coordinates for spot test locations (MnDOT, research team)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Coordinate with IC roller operator on how to collect, record, save, download and transfer data for this project (Contractor, MnDOT and research team)</td>
</tr>
<tr>
<td>First Visit</td>
<td>Subgrade compaction and tests</td>
<td>• Prepare and compact subgrade layer within the test section (Contractor, research team)</td>
</tr>
<tr>
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<td></td>
<td>• Install geophones at a depth of 24 in. and 6 in. from the top of subgrade</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Map the top of subgrade with IC roller (Contractor, research team)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Conduct in-situ testing with LWD/DCP (research team)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Conduct NDG tests (MnDOT) and obtain moisture samples for validation of NDG (research team)</td>
</tr>
<tr>
<td>Second Visit</td>
<td>Unbounded Aggregate Base (UAB) compaction and tests</td>
<td>• Pre-map subgrade within the test section (Contractor, research team)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Prepare and compact UAB within the test section (Contractor, research team)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Install geophone at a depth of 6 in. from the top of the aggregate base (research team)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Map the top of UAB with IC roller (Contractor, research team)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Conduct in-situ testing with LWD/DCP (research team)</td>
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<td>• Conduct NDG tests (MnDOT) and obtain moisture samples for validation of NDG (research team)</td>
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</table>
Steps of Field Tests

1. Install geophones in the subgrade
2. Map the subgrade surface with the instrumented IC roller
3. Conduct spot tests with nuclear density gauge (NDG), Lightweight deflectometer (LWD) and Dynamic Cone Penetrometer (DCP) at designated locations on subgrade
4. Spread and compact the unbound aggregate base (UAB)
5. Install geophones in the UAB
6. Map the UAB surface with the IC roller
7. Conduct spot tests with NDG, LWD and DCP at designated locations on UAB
Pre-Mapping and Mapping

- Existing Base
  - Equivalent modulus to roller influence depth

- Modulus of top layer
  - Equivalent modulus to roller influence depth

*not to scale
UTEP IC DAQ and Field Instrumentation

Data Acquisition Box and Laptop

*not to scale*
Field Instrumentation
IC Roller Tests

Smooth Drum IC Rollers

RTK GPS

Mounted Accelerometers

Accelerometers and Connections to DAQ

Mounting Accelerometers
Calibration of IC Model

Moving Direction

GPS Antenna
Roller DAQ
Mounted Accelerometer

h₁
h₂
Ground DAQ
Embedded Geophones

Displacement, mm
0.0
0.5
1.0
1.5
-2 -1 0 1 2
Distance from Drum, m

Field Data

Calibration

FE SSL Displacement, mm

Geophone Measured Peak Vertical Displacement, mm

Calibration of IC Model
IC Roller Compaction and Spot Tests
Local Calibration and Calculated Modulus

Local Calibration

ANN-Predicted Modulus (MPa)

Measured Modulus (MPa)

Level 5 ICMV Prototype
Data Reduction and Evaluation of the ICMV Systems

• Statistical analysis of all levels of ICMVs and other related measurements
• Correlation analyses among all levels of ICMVs vs. full set of spot tests
• Correlation analyses among all levels of ICMVs vs. reduced subsets of spot tests
• Evaluation of full-depth and layer-specific ICMVs
• Verification between Level 3-4 ICMVs and NCHRP 24-45 DAQs
• Comparison between Level 3-4 ICMVs and Level 1-2 ICMVs
Development of Final Report

• Framework for a future certification program for single-drum IC rollers
• Minimum requirements for correlation between ICMV and spot tests from a test strip for IC specification
• Selection of ICMV uniformity metrics and its minimum requirements for IC specification
• Proposed companion acceptance tests based on IC measurements in addition to conventional spot tests
• Whitepaper for standard/reference rollers.
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## Summary of Tasks and Deliverables

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<tr>
<th>Task</th>
<th>Description</th>
<th>Due Date</th>
<th>Deliverables</th>
</tr>
</thead>
</table>
| 1    | Project Management                 | Based on project schedule | One kick-off meeting minutes  
Five quarterly reports  
Oral report and presentation at two NRRA meetings |
| 2    | Level 3-4 ICMV Integration         | July 31, 2021          | Integrated Level 3-4 ICMV systems                                            |
| 3    | Roller Instrumentation and Field Tests | October 30, 2021     | Field test data                                                              |
THANK YOU!

NRRA Level 3-4 ICMV Webpage

https://www.dot.state.mn.us/mnroad/nrra/structure-teams/intelligent-construction/compaction.html